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Experimental and Theoretical Study of the Temperature Performance of Type-II Quantum Well Lasers

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Gregory Belenky, Mikhail V. Kisin, Sergey Suchalkin

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State University of New York at Stony Brook
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13. ABSTRACT (Maximum 200 words)
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Report Title

Experimental and Theoretical Study of the Temperature Performance of Type-II Quantum Well Lasers

ABSTRACT

The method of analyzing the temperature performance of type-II Interband Cascade (IC) GaSb-based semiconductor lasers has been developed. The method includes comparing the temperature-concentration dependence at the laser threshold with steady-state carrier heating characteristics. The number of cascades in prototype type-II IC lasers has been optimized with respect to the highest achievable operating temperature.

An ultra-sensitive single-pass measurement technique was developed to study optical absorption in thin-layered laser heterostructures. The presence of strong non-radiative recombination in type-II laser structures was demonstrated by our measurement technique. We show that thermally induced hole escape from the active quantum wells is responsible for deterioration of the optical emission both in type-I and type-II laser structures at elevated temperatures. New method of laser temperature characterization has been developed and tested on high-power diode arrays, which are especially vulnerable to heat generation and kinetics.

The study of type-II IC laser structures resulted in a proposal of a novel electrically tunable mid-IR light source. We have designed and experimentally demonstrated a working prototype of multimode electrically tunable IC laser operating in mid-infrared spectral region. The device demonstrates ultra-wide wavelength tuning in the range of up to 120 nm.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

[1]. S.Suchalkin, M.Kisin, S.Luryi, G.Belenky, F. Towner, J.D.Bruno, C. Monroy, and R.L.Tober, "Wavelength Tuning of Interband Cascade Laser Based on the Stark Effect", in “Future Trends in Microelectronics” ed. by S.Luryi, J.Xu, A.Zaslavsky, 2006.

[2]. S. Suchalkin, M.V. Kisin, S. Luryi, G. Belenky, J. Bruno, F.J. Towner, R. Tober, "Widely tunable type-II interband cascade laser", Appl. Phys. Lett. 88, No 3, 031103 (2006).

[3]. S. Suchalkin, L. Shterengas, M.V. Kisin, S. Luryi, G. Belenky, R. Kaspi, A. Ongstad, J.G.Kim, R.U.Martinelli, "Mechanism of the temperature sensitivity of mid-IR GaSb based semiconductor lasers", Appl. Phys. Lett. , vol. 87, No 4, 041102 (2005).

[4]. A. Gourevitch, B. Laikhtman, D. Westerfeld, D. Donetsky, G. Belenky, C. W. Trussell, Z. Shellenbarger, H. An, R. U. Martinelli, “Transient thermal analysis of InGaAsP-InP high-power diode laser arrays with different fill factors”, J. Appl. Phys., vol. 97, No 3, 084503 (2005).

[5]. B. Laikhtman, A. Gourevitch, D. Donetsky, D. Westerfeld, G. Belenky, “Current spread and overheating of high power laser bars”, J. Appl. Phys., vol. 95, No 8, pp. 3880-3889 (2004).

[6]. M. V. Kisin, S. D. Suchalkin, G. Belenky, J. D. Bruno, R. Tober, S. Luryi, "Analysis of the Temperature Performance of Type-II Interband Cascade Lasers", Appl. Phys. Lett. , vol. 85, No 19, pp. 4310-4312 (2004).

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(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

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[1]. S.D. Suchalkin, M.V. Kisin, S. Luryi, G. Belenky, J. Bruno, F.J. Towner, C. Monroy, R. Tober “Electrically Tunable Interband Cascade Laser” (invited), Optics East, Boston, Massachusetts, October 1-4, 2006.
[2]. M.V. Kisin, L. Shterengas, J.G. Kim, and G. Belenky, "Enhancement of optical gain in Sb-based MIR diode lasers", 20th IEEE International Semiconductor Laser Conference, Hawaii, September 17-23, 2006; Semiconductor Laser Conference, 2006. Conference Digest. 2006 IEEE 20th International Sept. 17-21, 2006 Page(s):89 – 90.
[3]. L. Shterengas, A. Ongstad, R. Kaspi, S. Suchalkin, G. Belenky, M.V. Kisin, D. Donetsky, “Electron and Hole Energy Relaxation in InGaAsSb/InAs/InGaSb Type-II QW Laser Heterostructures”, Electronic Materials Conference, Pennsylvania State University, Pennsylvania, USA, June 28-30 (2006).
[4]. L. Shterengas, A. Ongstad, R. Kaspi, S. Suchalkin, G. Belenky, M. Kisin, D. Donetsky, "Carrier capture in InGaAsSb/InAs/InGaSb type-II QW laser heterostructures", CLEO, 2006.
[5]. M.V. Kisin, S. Suchalkin, G. Belenky, "Stark effect tunable QCL", 8th International Conference on Intersubband Transitions in Quantum Wells ITQW’2005, North Falmouth, MA, September 11 – 16, 2005.
[6]. A. Gourevitch, D. Donetsky, G. Belenky B. Laikhtman, D. Westerfeld, Z. Shellenbarger, H. An, R. U. Martinelli, C. W. Trussell, ”Transient thermal analysis of 1.47 ?m high power diode laser arrays“, “Proceeding of the Solid State and Diode Laser Technology Review, SSDLTR-04”, P-9, Albuquerque, New Mexico, 8-10 June 2004.
[7]. G.L. Belenky, L. Shterengas, J.G. Kim, R. Martinelli, S.Suchalkin, M.V. Kisin, "GaSb-based lasers for spectra region 2-4 µm: challenges and limitations", Photonics West, January 21, 2005, San Jose, CA, USA; Proc. SPIE, v. 5732, pp. 169-174 (2005).
[8]. S. Suchalkin, M.V. Kisin, G. Belenky, S. Luryi, Y. Vasilyev, John Bruno, Fred Towner, Richard Tober, " Electrically Tunable Cascaded mid-IR Type II Light Source", Photonics West, January 21, 2005, San Jose, CA; Proc. SPIE v. 5738, pp. 130-137 (2005).

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NAME	PERCENT_SUPPORTED	National Academy Member
Gregory Belenky	0.08	No
FTE Equivalent:	**0.08**	
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Names of personnel receiving PHDs

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Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED	
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FTE Equivalent:	**1.00**	
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Sincerely,

Gregory Belenky

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12 a. DISTRIBUTION / AVAILABILITY STATEMENT
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13. ABSTRACT (Maximum 200 words)

The method of analyzing the temperature performance of type-II Interband Cascade (IC) GaSb-based semiconductor lasers has been developed. The method includes comparing the temperature-concentration dependence at the laser threshold with steady-state carrier heating characteristics. The number of cascades in prototype type-II IC lasers has been optimized with respect to the highest achievable operating temperature.
An ultra-sensitive single-pass measurement technique was developed to study optical absorption in thin-layered laser heterostructures. The presence of strong non-radiative recombination in type-II laser structures was demonstrated by our measurement technique. We show that thermally induced hole escape from the active quantum wells is responsible for deterioration of the optical emission both in type-I and type-II laser structures at elevated temperatures. New method of laser temperature characterization has been developed and tested on high-power diode arrays, which are especially vulnerable to heat generation and kinetics.
The study of type-II IC laser structures resulted in a proposal of a novel electrically tunable mid-IR light source. We have designed and experimentally demonstrated a working prototype of multimode electrically tunable IC laser operating in mid-infrared spectral region. The device demonstrates ultra-wide wavelength tuning in the range of up to 120 nm.

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Experimental and Theoretical Study of the Temperature Performance of Type-II Quantum Well Lasers

Final Progress Report

09/01/2003 –04/31/07

Gregory Belenky, Mikhail Kisin, and Sergey Suchalkin

Abstract

The method of analyzing the temperature performance of type-II Interband Cascade (IC) GaSb-based semiconductor lasers has been developed. The method includes comparing the temperature-concentration dependence at the laser threshold with steady-state carrier heating characteristics. The number of cascades in prototype type-II IC lasers has been optimized with respect to the highest achievable operating temperature.

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The study of type-II IC laser structures resulted in a proposal of a novel electrically tunable mid-IR light source. We have designed and experimentally demonstrated a working prototype of multimode electrically tunable IC laser operating in mid-infrared spectral region. The device demonstrates ultra-wide wavelength tuning in the range of up to 120 nm.

Statement of the problem studied

Mid-infrared (MIR) spectral range from 3 to 5 µm corresponding to atmospheric transparency window is of special importance for military application such as infrared countermeasures. Antimonide-based type-II quantum well (QW) lasers have shown great promise for development of highly efficient high-temperature operating high-power semiconductor optical sources in this spectral range. To take full advantage of the unique opportunities offered by type-II GaSb-based structures more detailed information about the optical properties, carrier dynamics and recombination mechanisms in type-II lasers is required. The sources of temperature sensitivity of type-II GaSb-based MIR lasers, which are manifested by low T_0 values and rapidly decreasing power slope efficiency with temperature, are to be understood. Identification and suppression of the mechanisms of thermal sensitivity and optical loss in electrically pumped cascade lasers and/or optically pumped quantum well lasers is vital for future device development in 3 to 5 µm wavelength range. We plan to perform experimental and theoretical study of the temperature performance of type-II Interband Cascade (IC) GaSb-based semiconductor lasers which are most promising light source in 3 to 5 µm wavelength range and to fulfill their potentials as efficient CW roomtemperature operating mid-infrared optoelectronic devices. We plan also to investigate the new applications of these devices in MIR wavelength range.

The major technical objectives of the proposed work are:

- To identify the nature of threshold temperature sensitivity in type-II interband cascade MIR lasers.
- To carry out detailed theoretical and experimental study of the temperature dependence of type-II laser characteristics, such as optical and internal losses, net modal and differential gain, threshold current, injection and internal efficiency.
- To determine the way to improve the efficiency of type-II MIR IC laser structures. Based on the experimental and theoretical results of the proposed program, improved design of the laser active region will increase the high-temperature limit of operation of existing type-II lasers and bring it up to the range of electrical cooling reach (250-300K).
- To find new applications for the type-II IC lasers in MIR wavelength range.

Summary of project results

1. We have developed a theoretical model and analyzed the temperature performance of type-II Interband Cascade (IC) GaSb-based semiconductor lasers by comparing the temperature-concentration dependence at the laser threshold with steady-state carrier heating characteristics. We have shown that the number of cascades for type-II IC lasers can be optimized with respect to the highest achievable operating temperature. The low material gain characteristic of type-II heterostructures and the high resistance of the thermal link to the heat sink are primarily responsible for limiting the continuous-wave (CW) operation to low temperatures. These theoretical conclusions are in excellent agreement with our experimental results obtained for 3.7 μm type-II IC lasers. For details see Ref. [1] (reprint submitted) and Interim Progress Report [1].

2. We have experimentally investigated the sources of temperature sensitivity of the threshold current in type-II mid-IR GaSb-based semiconductor lasers. To study the optical absorption in thin layered laser heterostructures, we have developed and utilized a special ultra-sensitive single-pass measurement technique which allows absorption measurements even in single-quantum-well laser heterostructures. The interband optical absorption measurements provide direct information about the optical matrix elements in laser structures. We have shown that the difference in the optical matrix elements in type-I and type-II "W"-designed laser heterostructures is not responsible for strong temperature sensitivity of type-II laser threshold. We demonstrate that thermally induced hole escape from the active quantum wells is the most important process which strongly deteriorates the optical emission in both type heterostructures. Our experiments show that the temperature decay of PL is noticeably stronger for type-II samples, which indicates the presence of strong non-radiative recombination in these structures at elevated temperatures. For details see Ref. [2] (reprint submitted) and Interim Progress Report [2].

3. We also have studied, both experimentally and theoretically, the temperature kinetics in the mid-IR laser arrays. Original experimental and theoretical approaches to laser temperature characterization have been developed and tested on high-power diode arrays, which are especially vulnerable to heat generation and kinetics. The temperature kinetics in the laser active region was obtained by measuring the temporal evolution of the laser spectrum during a

single current pulse. We showed that the transient heating process can be divided into three time periods with each period determined by its own heat transport condition. During the first period, the bar structure is heated and the heat fluxes from individual stripes of the laser bar overlap, producing the nearly uniform heat flux. The duration of this period is determined by the geometry of the laser bar and its thermal diffusivity. We demonstrated that in this initial period of time evolution, the heat propagates within the laser bar structure, and the fill factor of the array strongly affects the active-region temperature rise. For details see Ref. [3,4] (reprints submitted) and Interim Progress Report [3].

4. Our study of type-II IC semiconductor heterostructures resulted in proposal of a novel electrically tunable mid-IR light source. The active area of the new device consists of several cascades with optically active type-II semiconductor quantum wells. Tunable electric field across the active layers of each cascade is created by the process of electron and hole accumulation in accumulating (reservoir) quantum wells separated from the optically active layers by specially designed tunnel barriers. The energy separation between electron and hole levels in active layers and, hence, the device emission wavelength can be tuned by changing the bias current through the structure. Our proposal combines the advantage of strong wavelength tuning due to the linear Stark effect with the presence of separate charge accumulation layers, which enable the wavelength tuning without substantial change of the optical loss. Our experimental results justify the potentials of the proposed design. In IC structures grown by MBE and processed in deep etched stripes we have observed a blue shift of the electroluminescence (EL) line in full agreement with that expected from the linear Stark effect. At higher bias currents the laser generation was observed. At T=80K the EL wavelength shifts from 2.79 µm to 2.38 µm (total tuning about 80 meV) as the bias current increases from 97 mA to 418 mA, which provides the record combination of the wide tuning range and low relative change of the bias current. Starting from these results, we have designed and experimentally demonstrated a working prototype of multimode electrically tunable IC laser operating in mid-infrared spectral range. Our device demonstrates ultra-wide wavelength tuning in the range of up to 120 nm. For details see Ref. [5] (reprint submitted) and Interim Progress Report [4].

List of Publications

(a) Papers published in peer-reviewed journals

[1]. S.Suchalkin, M.Kisin, S.Luryi, G.Belenky, F. Towner, J.D.Bruno, C. Monroy, and R.L.Tober, "Wavelength Tuning of Interband Cascade Laser Based on the Stark Effect", in “Future Trends in Microelectronics” ed. by S.Luryi, J.Xu, A.Zaslavsky, 2006.

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[3]. S. Suchalkin, L. Shterengas, M.V. Kisin, S. Luryi, G. Belenky, R. Kaspi, A. Ongstad, J.G.Kim, R.U.Martinelli, "Mechanism of the temperature sensitivity of mid-IR GaSb based semiconductor lasers", Appl. Phys. Lett. , vol. 87, No 4, 041102 (2005).

[4]. A. Gourevitch, B. Laikhtman, D. Westerfeld, D. Donetsky, G. Belenky, C. W. Trussell, Z. Shellenbarger, H. An, R. U. Martinelli, “Transient thermal analysis of InGaAsP-InP high-power diode laser arrays with different fill factors”, J. Appl. Phys., vol. 97, No 3, 084503 (2005).

[5]. B. Laikhtman, A. Gourevitch, D. Donetsky, D. Westerfeld, G. Belenky, “Current spread and overheating of high power laser bars”, J. Appl. Phys., vol. 95, No 8, pp. 3880-3889 (2004).

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(b) Papers published in conference proceedings

[1]. S.D. Suchalkin, M.V. Kisin, S. Luryi, G. Belenky, J. Bruno, F.J. Towner, C. Monroy, R. Tober “Electrically Tunable Interband Cascade Laser” (invited), Optics East, Boston, Massachusetts, October 1-4, 2006.

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[3]. L. Shterengas, A. Ongstad, R. Kaspi, S. Suchalkin, G. Belenky, M.V. Kisin, D. Donetsky, “Electron and Hole Energy Relaxation in InGaAsSb/InAs/InGaSb Type-II QW Laser Heterostructures”, Electronic Materials Conference, Pennsylvania State University, Pennsylvania, USA, June 28-30 (2006).

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[5]. M.V. Kisin, S. Suchalkin, G. Belenky, "Stark effect tunable QCL", 8th International Conference on Intersubband Transitions in Quantum Wells ITQW’2005, North Falmouth, MA, September 11 – 16, 2005.

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[7]. G.L. Belenky, L. Shterengas, J.G. Kim, R. Martinelli, S.Suchalkin, M.V. Kisin, "GaSb-based lasers for spectra region 2-4 µm: challenges and limitations", Photonics West, January 21, 2005, San Jose, CA, USA; Proc. SPIE, v. 5732, pp. 169-174 (2005).

[8]. S. Suchalkin, M.V. Kisin, G. Belenky, S. Luryi, Y. Vasilyev, John Bruno, Fred Towner, Richard Tober, " Electrically Tunable Cascaded mid-IR Type II Light

Source", Photonics West, January 21, 2005, San Jose, CA; Proc. SPIE v. 5738, pp. 130-137 (2005).

(c) Papers presented at meetings, but not published in conference proceedings

[1]. S.D. Suchalkin, M.V. Kisin, S. Luryi, G. Belenky, J. Bruno, F.J. Towner, , R. Tober, "Widely tunable type-II interband cascade laser", Research Workshop Future Trends in Microelectronics, Crete, Greece, June 26-30, 2006.

[2]. M.V. Kisin, S.D. Suchalkin, S. Luryi, G. Belenky, J. Bruno, F.J. Towner, R. Tober, "Electrically Tunable Cascade Laser", 2nd International Workshop on Quantum Cascade Lasers, Brindizi, Italy, September 6-9, 2006.

(d) Manuscripts submitted, but not published

none

(e) Technical reports submitted to ARO

[1]. DAAD190310259 Interim Progress Report, December 31, 2003

[2]. DAAD190310259 Interim Progress Report, September 15, 2004

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[4]. DAAD190310259 Interim Progress Report, August 15, 2006

[5]. DAAD190310259 Final Progress Report, May 31, 2007

List of participating scientific personnel

Prof. Gregory Belenky

Dr. Mikhail Kisin

Dr. Sergey Suchalkin

Technology Transfers and Inventions

US Patent application: G. Belenky, J. Bruno, M. Kisin, S. Luryi, L. Shterengas, S. Suchalkin, R. Tober "Semiconductor light source with electrically tunable emission wavelength" (joint efforts of SUNY, Maxion Technologies Inc., and Army Research Laboratory). The reference number of SUNY Office of Technology Licensing and Industry Relations is R-7762, receiving date is May 17, 2004. US provisional Patent application No 60/602,750 filed August 19, 2004.

References

[1]. M. V. Kisin, S. D. Suchalkin, G. Belenky, J. D. Bruno, R. Tober, S. Luryi, "Analysis of the Temperature Performance of Type-II Interband Cascade Lasers", Appl. Phys. Lett. , vol. 85, No 19, pp. 4310-4312 (2004).

[2]. S. Suchalkin, L. Shterengas, M.V. Kisin, S. Luryi, G. Belenky, R. Kaspi, A. Ongstad, J.G.Kim, R.U.Martinelli, "Mechanism of the temperature sensitivity of mid-IR GaSb based semiconductor lasers", Appl. Phys. Lett. , vol. 87, No 4, 041102 (2005).

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1.a. NAME OF CONTRACTOR/SUBCONTRACTOR	c. CONTRACT NUMBER	2.a. NAME OF GOVERNMENT PRIME CONTRACTOR	c. CONTRACT NUMBER	3. TYPE OF REPORT *(X one)*
Research Foundation of SUNY	DAAD 190310259	US Army Research Office	DAAD 190310259	a. INTERIM ☐ b. FINAL ✘

b. ADDRESS *(Include ZIP Code)*	d. AWARD DATE *(YYYYMMDD)*	b. ADDRESS *(Include ZIP Code)*	d. AWARD DATE *(YYYYMMDD)*	4. REPORTING PERIOD *(YYYYMMDD)*
Office of Research Services Stony Brook, NY, 1794-3366	2003/09/01	P.O. Box 12211 Research Triangle Park, NC 27709-2211	2003/09/01	a. FROM 2003/09/01 b. TO 2007/04/31

SECTION I - SUBJECT INVENTIONS

5. "SUBJECT INVENTIONS" REQUIRED TO BE REPORTED BY CONTRACTOR/SUBCONTRACTOR *(If "None," so state)*

NAME(S) OF INVENTOR(S) *(Last, First, Middle Initial)* a.	TITLE OF INVENTION(S) b.	DISCLOSURE NUMBER, PATENT APPLICATION SERIAL NUMBER OR PATENT NUMBER c.	ELECTION TO FILE PATENT APPLICATIONS *(X)* d. (1) UNITED STATES (a) YES	(1) UNITED STATES (b) NO	(2) FOREIGN (a) YES	(2) FOREIGN (b) NO	CONFIRMATORY INSTRUMENT OR ASSIGNMENT FORWARDED TO CONTRACTING OFFICER *(X)* e. (a) YES	e. (b) NO
G. Belenky, J. Bruno, M. Kisin, S. Luryi,	Semiconductor light source with electrically	US provisional	✘				✘	

f. EMPLOYER OF INVENTOR(S) NOT EMPLOYED BY CONTRACTOR/SUBCONTRACTOR	
(1) (a) NAME OF INVENTOR *(Last, First, Middle Initial)* J. Bruno	(2) (a) NAME OF INVENTOR *(Last, First, Middle Initial)* R. Tober
(b) NAME OF EMPLOYER Maxion Technologies Inc.	(b) NAME OF EMPLOYER Army Research Laboratory
(c) ADDRESS OF EMPLOYER *(Include ZIP Code)* Maxion Technologies Inc., Hyattsville, MD 20782	(c) ADDRESS OF EMPLOYER *(Include ZIP Code)* Army Research Lab, Adelphi, MD 20873

g. ELECTED FOREIGN COUNTRIES IN WHICH A PATENT APPLICATION WILL BE FILED	
(1) TITLE OF INVENTION	(2) FOREIGN COUNTRIES OF PATENT APPLICATION

SECTION II - SUBCONTRACTS *(Containing a "Patent Rights" clause)*

6. SUBCONTRACTS AWARDED BY CONTRACTOR/SUBCONTRACTOR *(If "None," so state)*

NAME OF SUBCONTRACTOR(S) a.	ADDRESS *(Include ZIP Code)* b.	SUBCONTRACT NUMBER(S) c.	FAR "PATENT RIGHTS" d. (1) CLAUSE NUMBER	d. (2) DATE *(YYYYMM)*	DESCRIPTION OF WORK TO BE PERFORMED UNDER SUBCONTRACT(S) e.	SUBCONTRACT DATES *(YYYYMMDD)* f. (1) AWARD	f. (2) ESTIMATED COMPLETION
none							

SECTION III - CERTIFICATION

7. CERTIFICATION OF REPORT BY CONTRACTOR/SUBCONTRACTOR *(Not required if: (X as appropriate))* ☐ SMALL BUSINESS or ☐ NONPROFIT ORGANIZATION

I certify that the reporting party has procedures for prompt identification and timely disclosure of "Subject Inventions," that such procedures have been followed and that all "Subject Inventions" have been reported.

a. NAME OF AUTHORIZED CONTRACTOR/SUBCONTRACTOR OFFICIAL *(Last, First, Middle Initial)*	b. TITLE	c. SIGNATURE	d. DATE SIGNED
G. Belenky	Prof.		05/28/2001

DD FORM 882, DEC 2001 PREVIOUS EDITION IS OBSOLETE.

Reset

DD FORM 882 INSTRUCTIONS

GENERAL

This form is for use in submitting INTERIM and FINAL invention reports to the Contracting Officer and for use in reporting the award of subcontracts containing a "Patent Rights" clause. If the form does not afford sufficient space, multiple forms may be used or plain sheets of paper with proper identification of information by item number may be attached.

An INTERIM report is due at least every 12 months from the date of contract award and shall include (a) a listing of "Subject Inventions" during the reporting period, (b) a certification of compliance with required invention identification and disclosure procedures together with a certification of reporting of all "Subject Inventions," and (c) any required information not previously reported on subcontracts containing a "Patent Rights" clause.

A FINAL report is due within 6 months if contractor is a small business firm or domestic nonprofit organization and within 3 months for all others after completion of the contract work and shall include (a) a listing of all "Subject Inventions" required by the contract to be reported, and (b) any required information not previously reported on subcontracts awarded during the course of or under the contract and containing a "Patent Rights" clause.

While the form may be used for simultaneously reporting inventions and subcontracts, it may also be used for reporting, promptly after award, subcontracts containing a "Patent Rights" clause.

Dates shall be entered where indicated in certain items on this form and shall be entered in six or eight digit numbers in the order of year and month (YYYYMM) or year, month and day (YYYYMMDD). Example: April 1999 should be entered as 199904 and April 15, 1999 should be entered as 19990415.

1.a. Self-explanatory.

1.b. Self-explanatory.

1.c. If "same" as Item 2.c., so state.

1.d. Self-explanatory.

2.a. If "same" as Item 1.a., so state.

2.b. Self-explanatory.

2.c. Procurement Instrument Identification (PII) number of contract (DFARS 204.7003).

2.d. through 5.e. Self-explanatory.

5.f. The name and address of the employer of each inventor not employed by the contractor or subcontractor is needed because the Government's rights in a reported invention may not be determined solely by the terms of the "Patent Rights" clause in the contract.

Example 1: If an invention is made by a Government employee assigned to work with a contractor, the Government rights in such an invention will be determined under Executive Order 10096.

Example 2: If an invention is made under a contract by joint inventors and one of the inventors is a Government employee, the Government's rights in such an inventor's interest in the invention will also be determined under Executive Order 10096, except where the contractor is a small business or nonprofit organization, in which case the provisions of 35 U.S.C. 202(e) will apply.

5.g.(1) Self-explanatory.

5.g.(2) Self-explanatory with the exception that the contractor or subcontractor shall indicate, if known at the time of this report, whether applications will be filed under either the Patent Cooperation Treaty (PCT) or the European Patent Convention (EPC). If such is known, the letters PCT or EPC shall be entered after each listed country.

6.a. Self-explanatory.

6.b. Self-explanatory.

6.c. Self-explanatory.

6.d. Patent Rights Clauses are located in FAR 52.227.

6.e. Self-explanatory.

6.f. Self-explanatory.

7. Certification not required by small business firms and domestic nonprofit organizations.

7.a. through 7.d. Self-explanatory.